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ERRATA SHEET

Technical Report R-232

Make the following pen and ink changes:

1. Page 15; Figure 9

Change ordinate heading from "Disc Large Head (psi)"

to "Discharge Head (psi)"

2. Page 24; 4th paragraph; 4th line

Change – "...point 1 (Figure 11)."

to – "...point 2 (Figure 11)."

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R 232

Technical Report

BOOSTER STATIONS FOR 4-INCH SHIP-TO-SHORE FUEL DELIVERY SYSTEMS

19 February 1963

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

BOOSTER STATIONS FOR 4-INCH SHIP-TO-SHORE FUEL DELIVERY SYSTEMS

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Type B   Final Report

by

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ABSTRACT

To extend the effective delivery range of the 4-inch buoyant and bottom-laid fuel delivery systems beyond the current 5000-foot capability, NCEL developed a diesel-driven booster station and tested a gas-turbine-driven booster station. This report describes the design, development, and comparative evaluation of the two units.

INTRODUCTION

Modern military amphibious operations, involving wide dispersal and rapid lateral displacement of both combat and support forces, have placed tremendous importance on mobile, high-capacity ship-to-shore fuel transfer systems. A reel-laid hose system and a bottom-laid pipe system were developed by NCEL to fill these requirements.* The two systems are designed to deliver fuel from ship to shore up to a distance of 5000 feet, utilizing the pumps on the fuel-delivering tanker. The delivery rates vary from 280 to 180 gallons per minute for specific gravities of 0.70 to 0.85, respectively, for a tanker pressure of 100 psi.

Under certain hydrographic conditions, it may become necessary for a tanker to moor at a distance greater than 5000 feet from shore to obtain sufficient depth for safe operation. In this case, a booster station must be introduced into the system to maintain the fuel delivery rate at the shore terminus of the system. To extend the delivery range of the two systems beyond the current 5000-foot capability, NCEL was directed to develop a floating booster station. Consideration was given to a diesel-driven and a gas-turbine-driven unit.

DESIGN CRITERIA

The following criteria were established by the Chief of Naval Operations for the design and development of a booster station. It must:

1. Be capable of pumping 350 gallons of gasoline per minute at a discharge pressure of 100 psi.

2. Be capable of continuous operation.

3. Be configured such that the pump can be mounted in an LCVP or larger craft, with no permanent alterations required to the craft.

* TR-164, Ship-to-Shore Bulk Fuel Delivery System (Buoyant), 10 November 1961.
TR-180, Ship-to-Shore Bulk Fuel Delivery System (Bottom-Laid), 31 January 1962.

4. Be carried to the objective area in the same manner as landing force naval equipment and be employed in landing craft or a pontoon barge as the situation dictates.

5. Be adaptable to a floating-hose or a bottom-laid pipe system.

6. Be skid-mounted.

PRELIMINARY INVESTIGATIONS

Prior to the design of the booster station, a study of the various conditions which would affect the booster pump in the fuel line was made. The conditions studied were: (a) the operational limits of the booster pump; (b) the maximum length to which a system could be extended; (c) communication and control; and (d) location of the booster station in the extended system.

Operational Limits

The design criteria stipulated that the booster station be compatible with the presently employed ship-to-shore fuel delivery systems. A review of the systems indicated: (1) the maximum pressure obtainable from an AOG (Auxiliary Oiler, Gasoline) is 125 psi (normal operation never exceeds 100 psi); (2) the 4-inch hose system has a specified 100-psi operating pressure, with pressures up to 125 psi permissible; and (3) the operating pressure of the 4-inch pipe system is 100 psi, but with higher operating pressures permissible. Based on the foregoing, it was decided that the normal operating range of the booster pump would be from a positive pressure of 15 psi at the intake side to a discharge pressure of 100 psi, with a maximum discharge pressure not to exceed 125 psi.

The 15-psi minimum pressure to the intake side of the booster pump was established to prevent collapsing of that section of the system comprised of buoyant hose and to forestall hunting by the pump to satisfy suction demands.

Communication and Control

The operation of a booster station in the system requires close communications and control. Any variations of pressure in a line may adversely affect the operation of the booster pump, with probable damage to the pump, the line, or both.

<u>Communication</u>. The submarine telephone system designed for use with the ship-to-shore fuel delivery systems offered the best method for maintaining continuous communication between operating points at the AOG, the booster station, and the shore.

Controls. It was determined that the booster station should have a safety-control system to protect the fuel line, the petroleum product, the pump, and the power unit under conditions of excessive pressure in the fuel line, a loss of intake pressure, a loss of discharge pressure, and excessive temperature in the pump.

Pump Location in the Extended System

The spacing of booster pumps in the fuel line was determined by the hydraulic design; i.e., by the head loss in the line for reasons of friction and elevation when the line is operating at the normal capacity for which it was designed. The design factors included topographic features of the pipeline route; type and properties of fuels to be pumped; required intake, discharge pressures, and other characteristics of the pumping units; and friction-head losses for the system.

Since the AOG, booster station, and shore receiving station are essentially at the same level, there will be little effect on the pressure due to changes in elevation.

The fuels to be pumped through the system range from gasoline (sp gr 0.70) to diesel fuel (sp gr 0.85). The friction-head losses of the present system while pumping these fuels, are illustrated by the curves in Figure 1. From these curves, the expected volume of fuel at the end of a given distance (up to 10,000 feet) can be estimated.

Assuming equivalent pressure losses in the hose and pipeline, a balanced system can be achieved by locating the booster station approximately midway between the AOG and the beach receiving station. By doing this, the discharge pressure of the line at the beach receiving station will not be excessive and the distance from the booster station will be such that excessive pressures will not be required to deliver the required volume of fuel.

Theoretical capacity versus distance curves for an extended 4-inch line with a booster station at the midpoint are shown in Figure 2. A series of theoretical curves to show the effect of more than one booster pump in the extended system is presented in Figure 3.

Extended Length

For logistic reasons, a 10,000-foot limit was placed on the length to which the system could be extended because an amphibious battalion will normally have only two 5000-foot systems (one buoyant and one bottom-laid) as a part of its complement. Also, it was expected that a safe water depth for the tanker would be obtained within this distance.

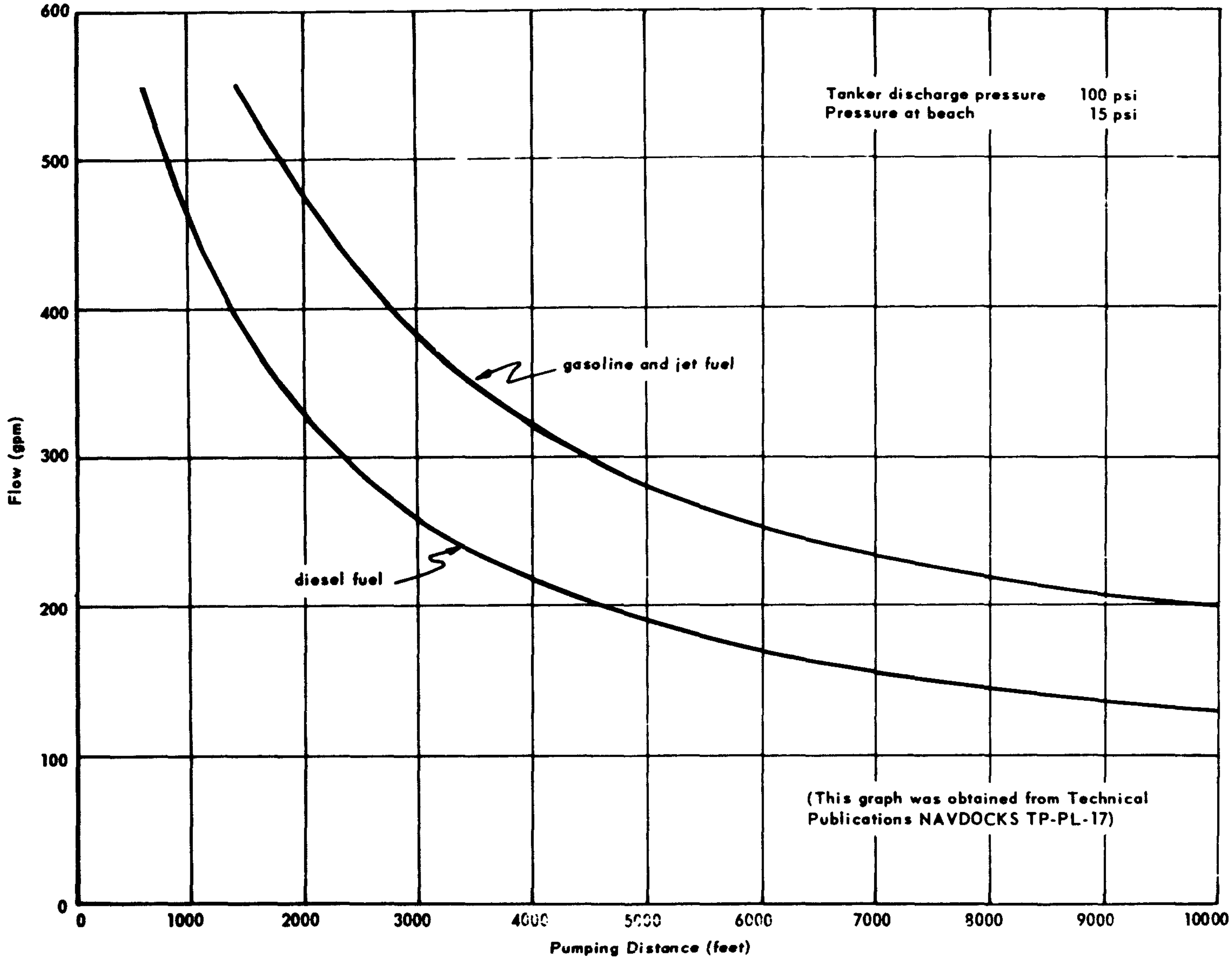


Figure 1. Capacity versus distance for 4-inch hose or pipe.

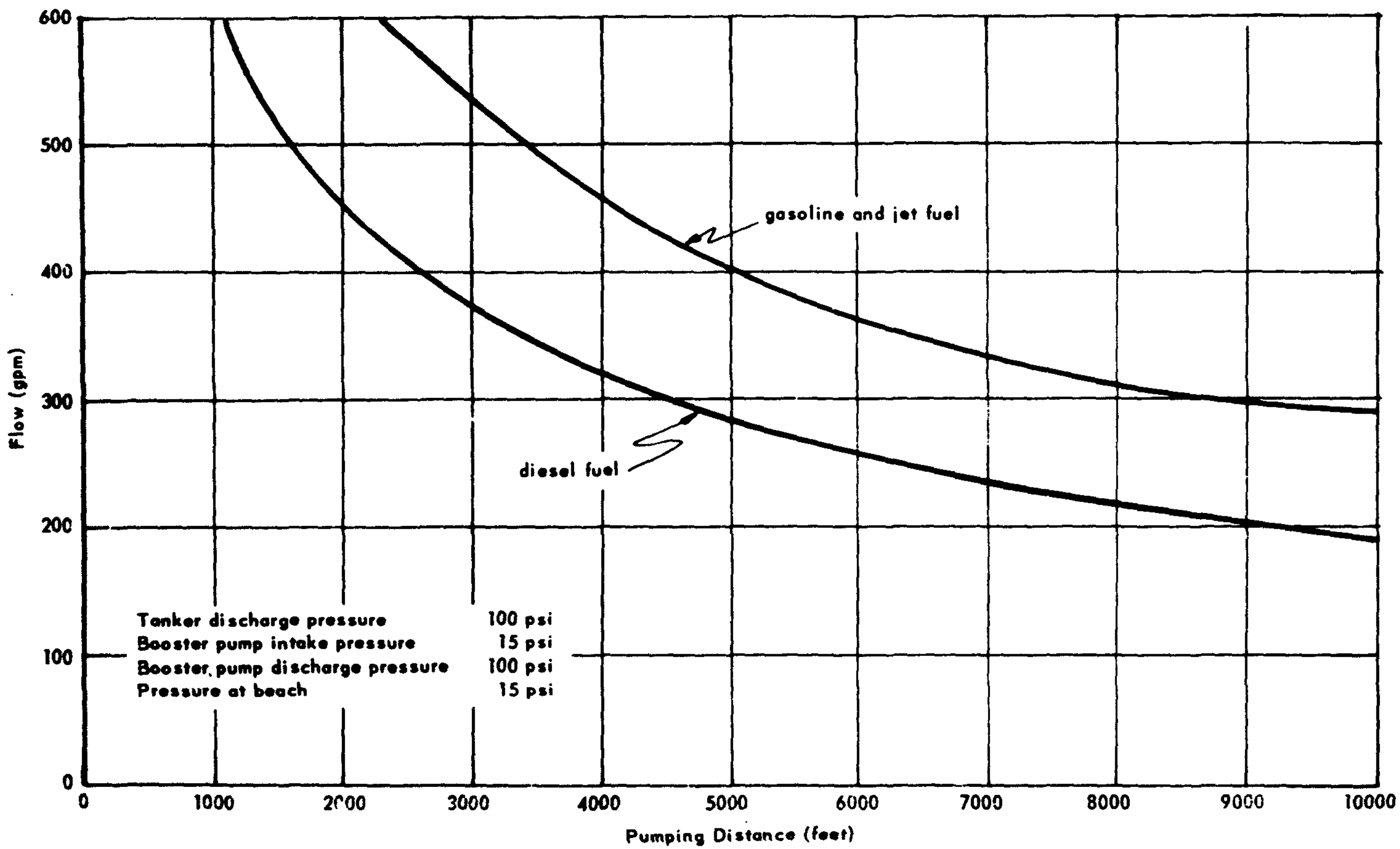


Figure 2. Calculated capacity versus distance for 4-inch hose or pipe with a booster station at the midpoint of the distance pumped.

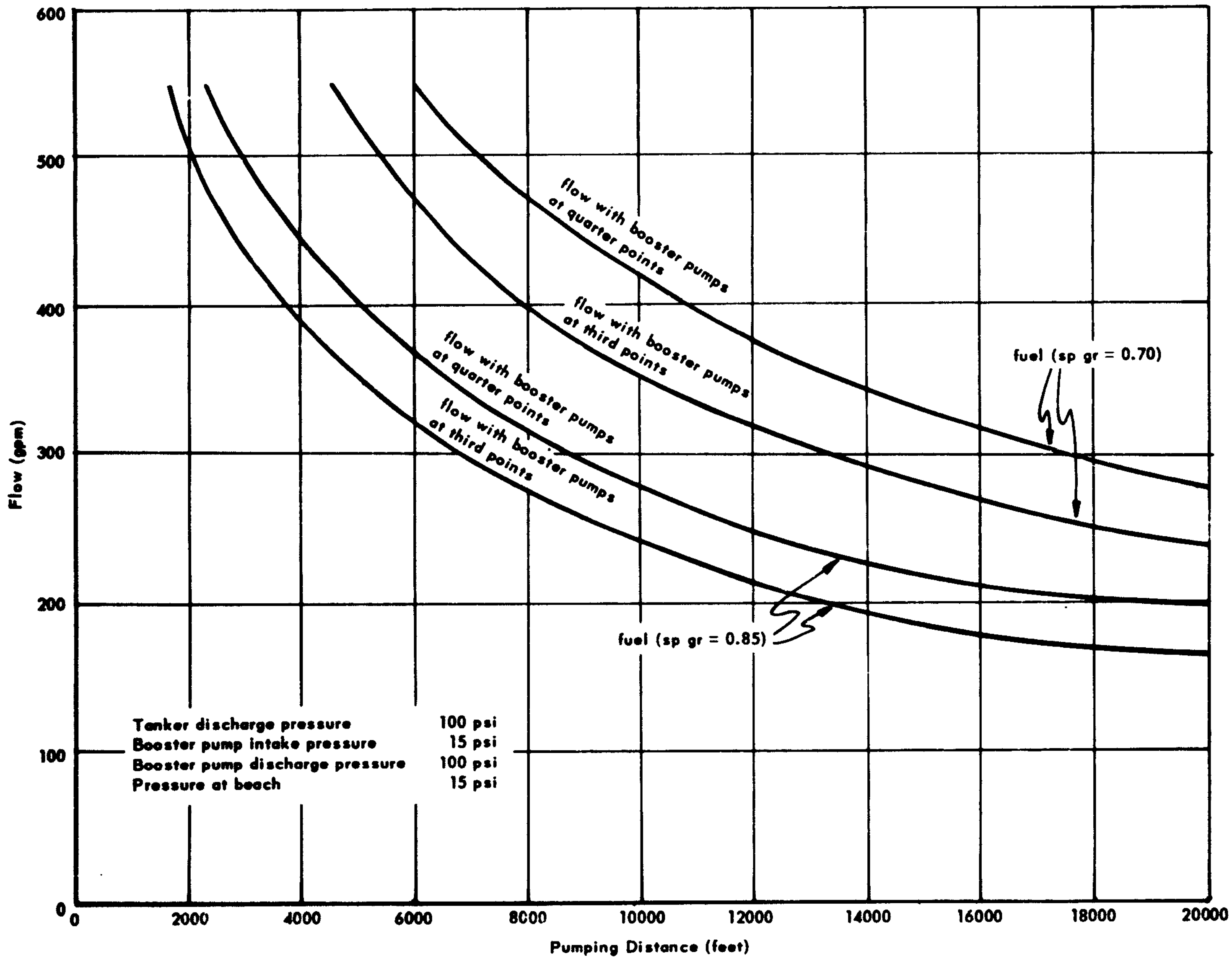


Figure 3. Curves showing the effect of added booster stations in the system.

If, however, extension of the system beyond 10,000-feet is required, it has been determined that one booster station is required for each 5000 feet of added length. The friction-head loss for a longer line requires excessive pumping pressures to deliver the required volume of fuel.

The installation technique to extend the present systems requires that the bottom-laid fuel line comprise the shoreward segment, and the buoyant fuel line the seaward segment, as shown in Figure 4. Further extensions would be made using the buoyant line.

BOOSTER SYSTEM

The system consists of a floating booster station for use with either a bottom-laid or a buoyant line as the shoreward segment, and a buoyant line as the seaward. Telephone communication is used between the operating points. Figure 4 shows a plan of the system.

At NCEL, the diesel booster station was housed in an LCM-6. The booster station with controls and fuel supply can also be mounted in an LCVP or LCM-8.

A three-point mooring, using 1/2-inch-diameter wire line with 200-pound STATO anchors, was designed to hold the booster station on position, at a depth of approximately 30 feet. Two lines are off the bow, 45 degrees to port and starboard, and a single line is off the stern. Each line is approximately 200 feet long.

The mooring was designed to restrict the LCM-6 to movements of up to 3 feet in sway, 25 degrees of yaw, and negligible surge, at forces in the lines not to exceed approximately 1000 pounds, of which 700 pounds is considered to be induced by environmental factors such as beam-on waves up to 6 feet high and 8-second period, winds up to 20 knots, bow-on currents of 2 knots, and a tide of 5 feet.

Two hand-operated winches are located at the bow and a small engine-powered winch is mounted at the stern to handle the respective anchors. The mooring can be installed by setting the stern anchor, using the craft's engine to move forward and set bow anchors, and positioning the craft with its engine or the stern winch. Adjustments to line tension can be made with the individual winches.

DIESEL-DRIVEN BOOSTER STATION

The diesel-driven booster station (Figures 5 and 6) is a self-contained unit mounted on a 3 x 10-foot base. It can be installed in a small craft for use with the ship-to-shore bulk fuel delivery system.

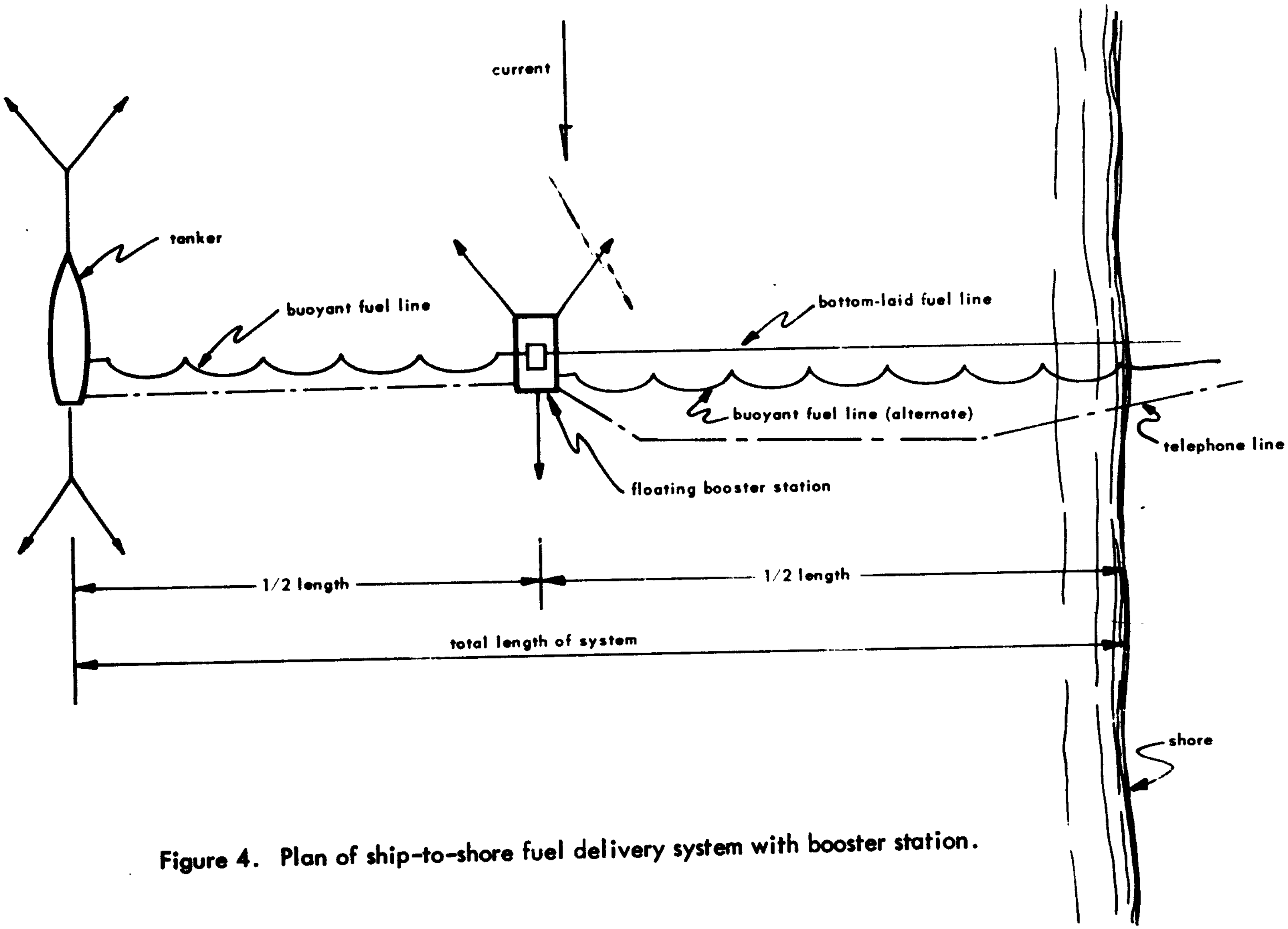


Figure 4. Plan of ship-to-shore fuel delivery system with booster station.

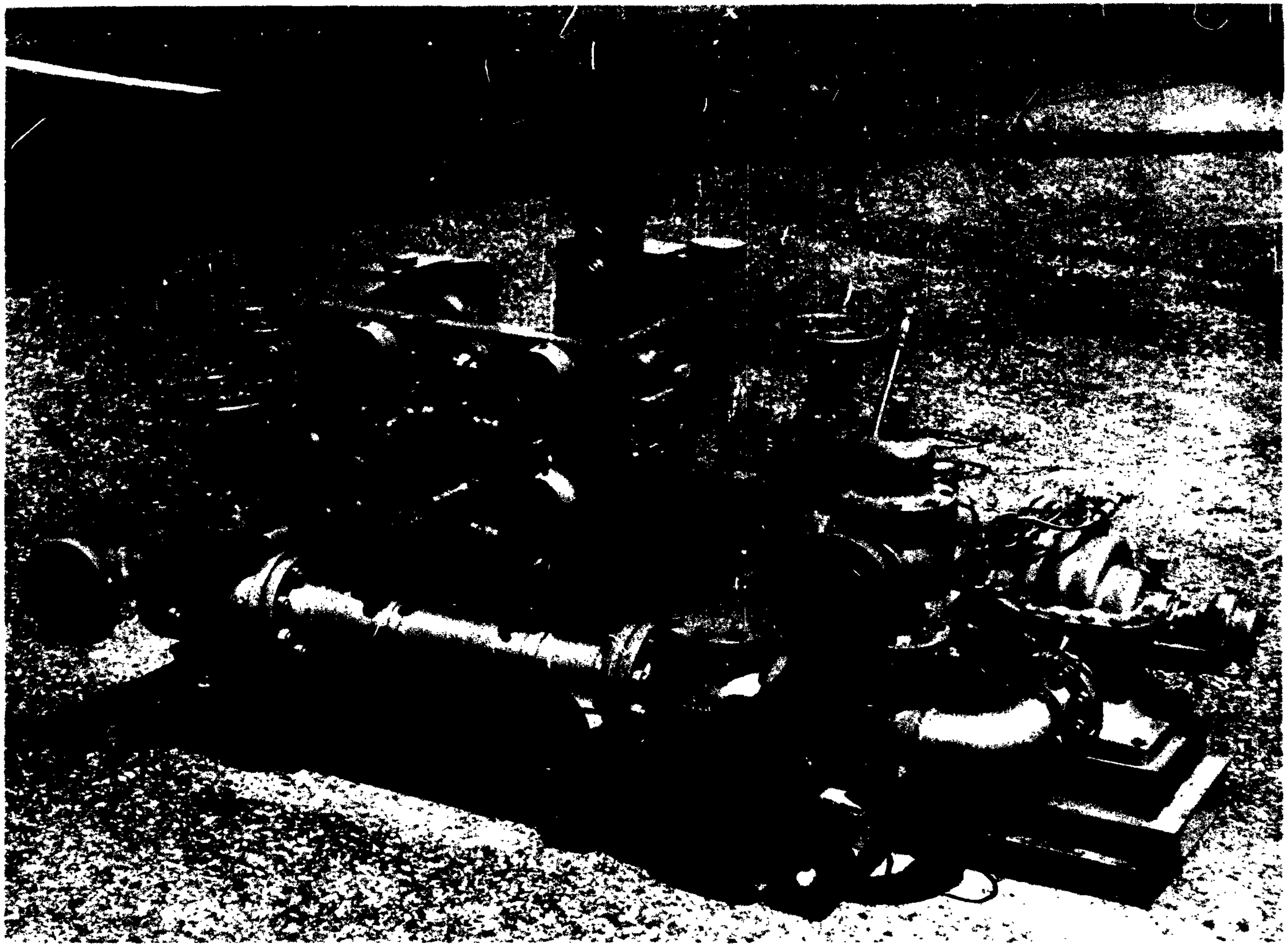
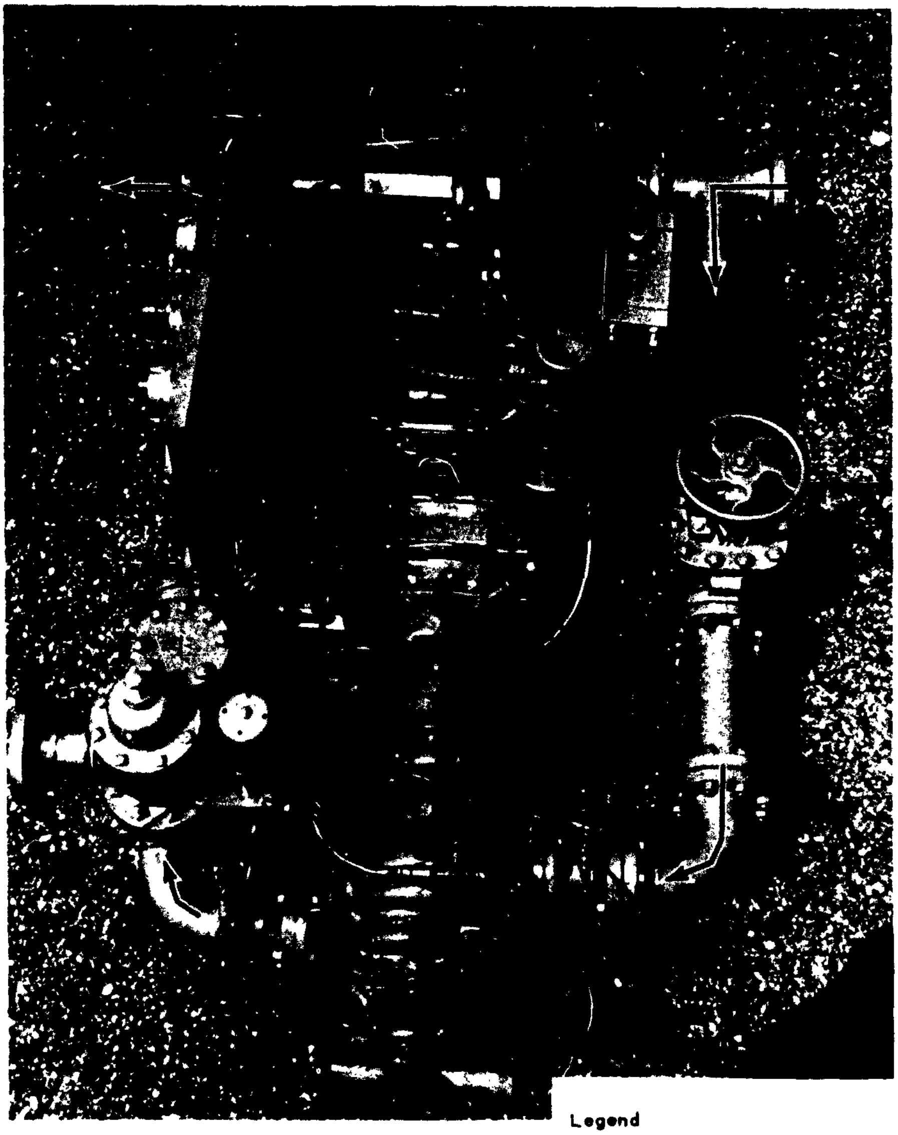


Figure 5. Diesel booster station.



Legend

1. Discharge pressure monitor
2. Discharge valve
3. Discharge
4. Control panel
5. Spark-arresting muffler
6. Intake
7. Control box
8. Diesel engine
9. Clutch
10. Intake pressure monitor
11. Pump
12. Temperature control

Figure 6. Plan view of the diesel booster station.

Pump

The pump is a Fairbanks-Morse Model No. 5972 with a 7.5-inch K3M1A impeller rated at 3460 rpm. The unit is complete with a metalized shaft and suitable packing for gasoline service.

Diesel Engine

The engine is a Continental Model HD-277, 4-cylinder diesel which drives the pump through a clutch and flexible coupling. A 1 to 1.5 speed increaser develops the required 3460-rpm pump speed with an engine speed of 2300 rpm. Safety features include a hydraulic starting system and a spark-arresting muffler.

Controls

The booster station is equipped with safety controls designed to protect the fuel line, the petroleum product, the pump, and the diesel engine. The safety controls protect against excessive pressure in the fuel-line system, intake failures, loss of dischage pressure due to a break in the fuel line on the discharge side of the pump, and excessive temperature in the pump. The control system operates in two stages: (1) the primary stage, which converts high temperature, low intake pressure, or high discharge pressure into a falling pressure condition; and (2) the secondary stage, which converts the falling pressure condition into a mechanical motion required to shut down the diesel engine. A manual engine shutdown, a control-cocking mechanism, and a control override are also provided.

The low-pressure relief valve (Figure 7) controls pressures monitored on the intake side of the pump (Figure 6); the high-pressure relief valve (Figure 7) controls pressures monitored downstream of the discharge valve (Figure 6). The temperature-control valve (Figure 6) monitors the temperature of the fluid being pumped. Operating pressure for the control system is obtained through the temperature-control valve.

The secondary stage (Figure 8) is energized with fluid from the primary stage. The pressurized fluid extends a hydraulic ram which activates the control system. The control is automatically cocked during starting of the diesel engine.

Excessive temperature or pressure or a loss of intake or discharge pressure closes the appropriate control valve, deactivating the secondary stage, and stopping the engine.

A detailed description of the controls and their operation is given in Appendix A. Operational techniques for starting and balancing the booster station and placing it on automatic control are given in Appendix B.

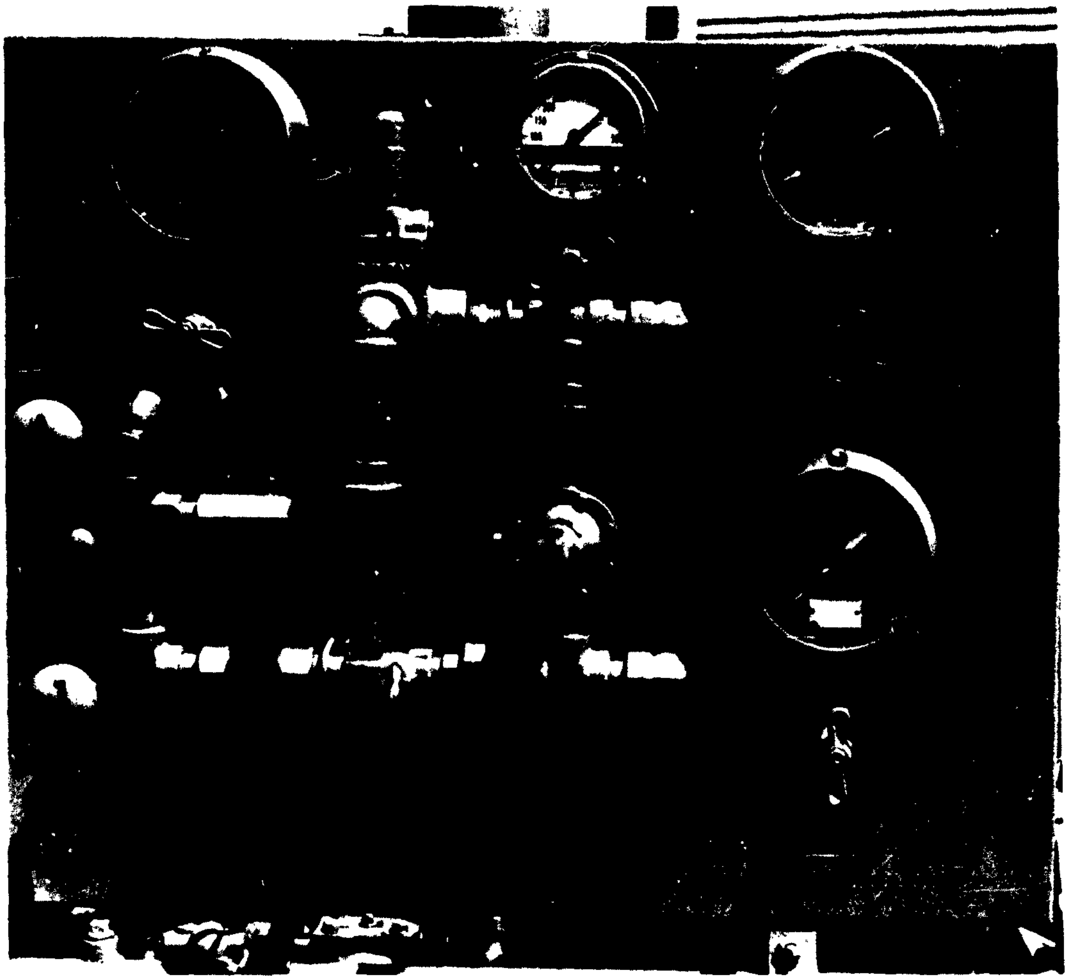
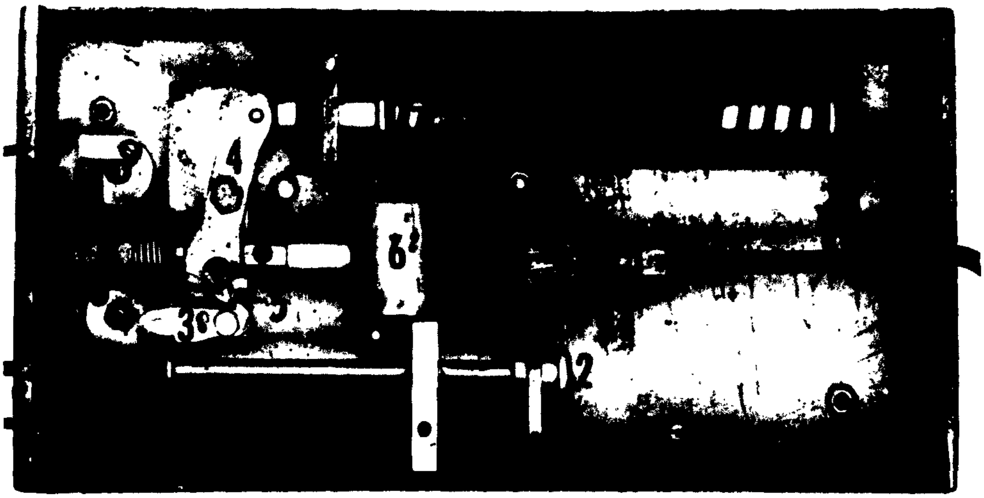


Figure 7. Diesel booster station control panel.

Legend

A. Engine throttle control
B. Pump discharge pressure gage
C. Pump intake pressure gage
D. High-pressure relief valve
E. Low-pressure relief valve
F. Control-circuit pressure gage, primary
G. Pressure in pump circuit gage
H. Engine operating gages
1. Automatic cocking rod
9. Manual shutdown control rod

Off Position



Automatic Position

Legend

1. Cocking rod and override control
2. Engine fuel-control rod
3. Trip
4. Lever arm
5. Latch
6. Hydraulic cylinder and ram
7. Buffer spring
8. Return spring
9. Manual shutdown control

Figure 8. Diesel booster station control.

Engineering Tests and Results

Tests of the booster station were conducted primarily to determine the reliability and effectiveness of the controls. A simple closed circuit was used for the tests. This consisted of a 1300-gallon reservior, a pump to simulate the tanker and the booster station, all connected with 4-inch hose. An additional valve was placed on the discharge side of the booster station to simulate the head loss of the operational length of fuel line to the shore. In the tests, diesel fuel was delivered in varying quantities to the booster pump while the operational pressure limits were maintained with the discharge valve.

Initial tests were made with pneumatically operated controls, which proved workable. However, due to limited capacity, the air tank had to be recharged frequently to maintain operating pressure for the controls. It was also found that the pump, while pumping diesel fuel in the specified range, was overloading the diesel engine.

As a result of the initial tests, the pneumatically operated controls were discarded. The air tank had an inadequate storage volume, and it would be impracticable to install a larger storage tank due to space and weight limitations. The addition of a small compressor on the diesel engine did not appear feasible as it would impose an additional load on an already overloaded engine. Hence, a hydraulic-mechanical control was adopted.

To prevent overloading, the size of the diesel engine could be increased, or, since the pump was capable of delivering fuel at pressures much higher than the imposed limit of 125 psi, the diameter of the pump impeller could be reduced. The impeller diameter, therefore, was reduced from 9 inches to 7.5 inches.

A series of tests was made to determine the pumping characteristics resulting from the new pump impeller size and the reliability of the hydraulic-mechanical control system. A 40-hour test in daily 8-hour shifts was made to determine the reliability of the booster station and its components.

The control system worked satisfactorily during the tests, and the pumping characteristics are summarized on the curve in Figure 9.

GAS-TURBINE-DRIVEN BOOSTER STATION

Following the investigation of the diesel-driven booster station, the use of a gas-turbine-driven booster station was investigated with a view toward obtaining the lightest practical unit. The Solar Aircraft Company of San Diego, California, was awarded a contract for the engineering development and fabrication of a gas-turbine booster pump.

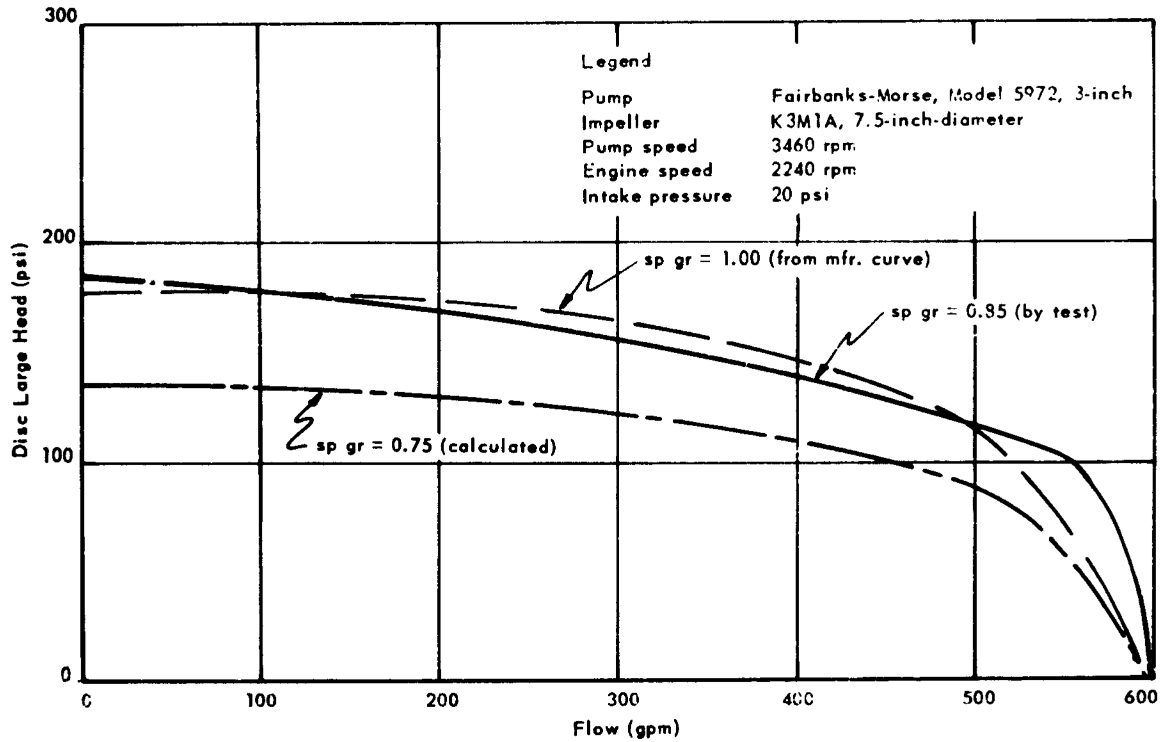


Figure 9. Pump characteristics — actual and theoretical.

The turbine booster station (Figure 10) is a self-contained unit that can be mounted on a small craft for use with the ship-to-shore bulk fuel delivery system. It consists essentially of a gas turbine, a pump, and controls.

Gas Turbine

A Solar Model T-41N-17 gas-turbine-driven generator assembly was used. It is basically a single-stage turbine engine generally used to supply auxiliary electrical power. The assembled unit, housed in a stainless-steel enclosure (see Figure 11), is mounted on a base supported on six vibration-isolating mounts. The turbine is rated at 50 horsepower at approximately 38,000 rpm. Operational characteristics are shown in Figure 12.

Pump

A J. C. Carter Company Model P/N6272 fuel-transfer pump with a 5.75-inch-diameter impeller operating at 6000 rpm is connected to the turbine through a 6.35-to-1 gear-reduction box.

Controls

There were two sets of controls for the unit. The first set was internal, to protect the turbine from damage by overspeeding, overheating, or overloading. The second set, an NCEL-designed pump control, supplemented the internal control system by protecting the fuel line and the turbine against a loss of intake pressure and a loss or excess of discharge pressure. Any of these conditions will cause the turbine to stop, either through the first or second set of controls. The control panel is shown in Figure 13.

TURBINE BOOSTER DESIGN

The manufacturer's operational characteristics of the turbine imposed special requirements:

1. An extremely confined turbine speed variation limit of plus or minus 2 percent of rated speed (overspeed/overload sensing)

2. A no-load start requirement

3. A direct connection from the pump to the turbine

4. Safety requirements (over and above those for the diesel unit)

Legend

1. Turbine exhaust
2. Turbine air intake
3. Scroll sump vent
4. Fuel tank
5. Supplementary fuel pumps
6. Carter pump drain valve
7. Pump drain sump
8. Turbine scroll sump

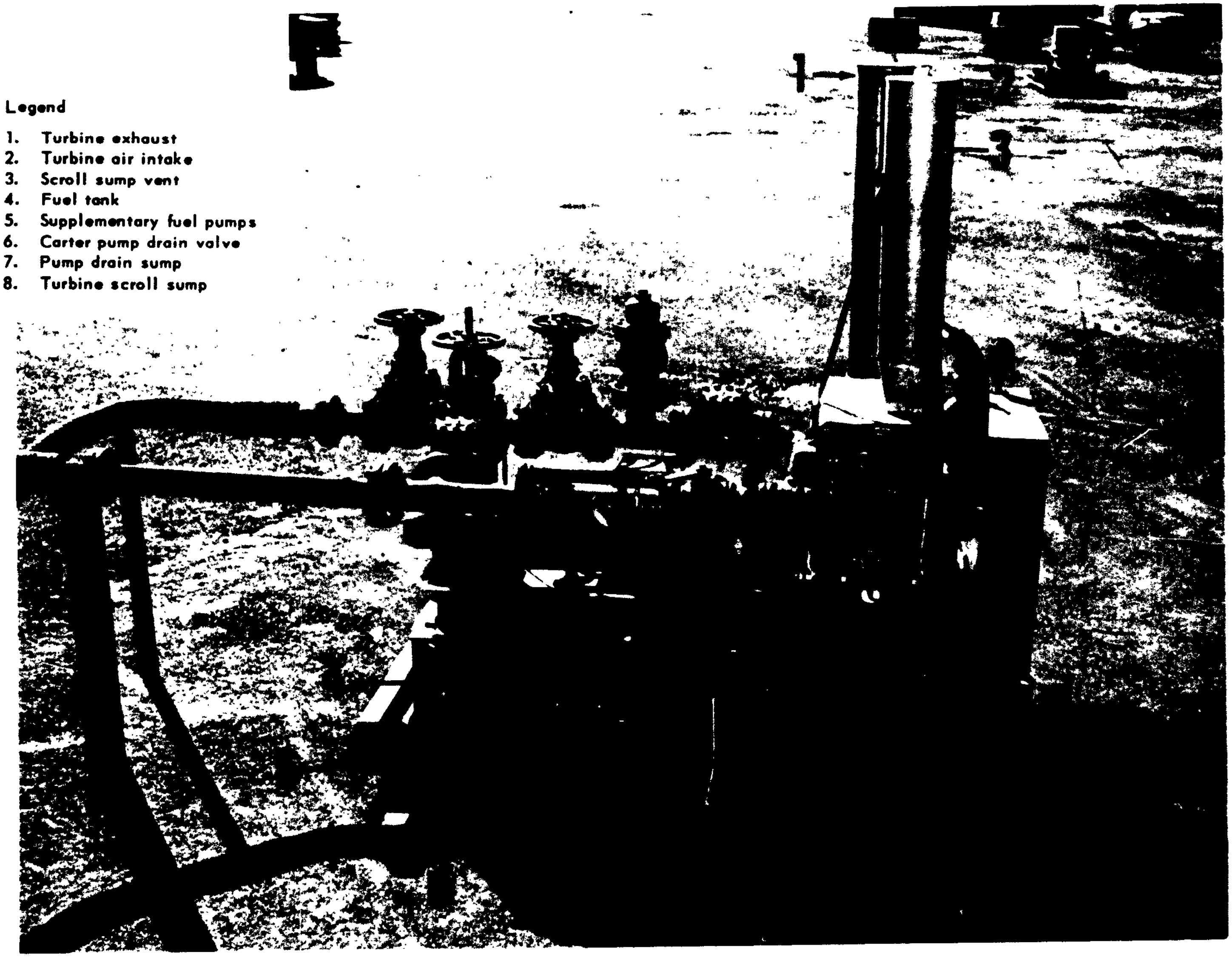


Figure 10. Gas turbine booster station.

Legend

- A. Turbine
- B. Fuel-transfer pump
- C. Quick-acting valve
- D. Discharge valve
- E. Check valve
- F. Safety valve
- G. High/low discharge control
- H. High/low intake control
- J. Fire extinguisher and warning light
- K. Test valve
- 1. Intake-pressure monitor
- 2. Discharge-pressure monitor

Figure 11. Plan view of gas turbine booster station.

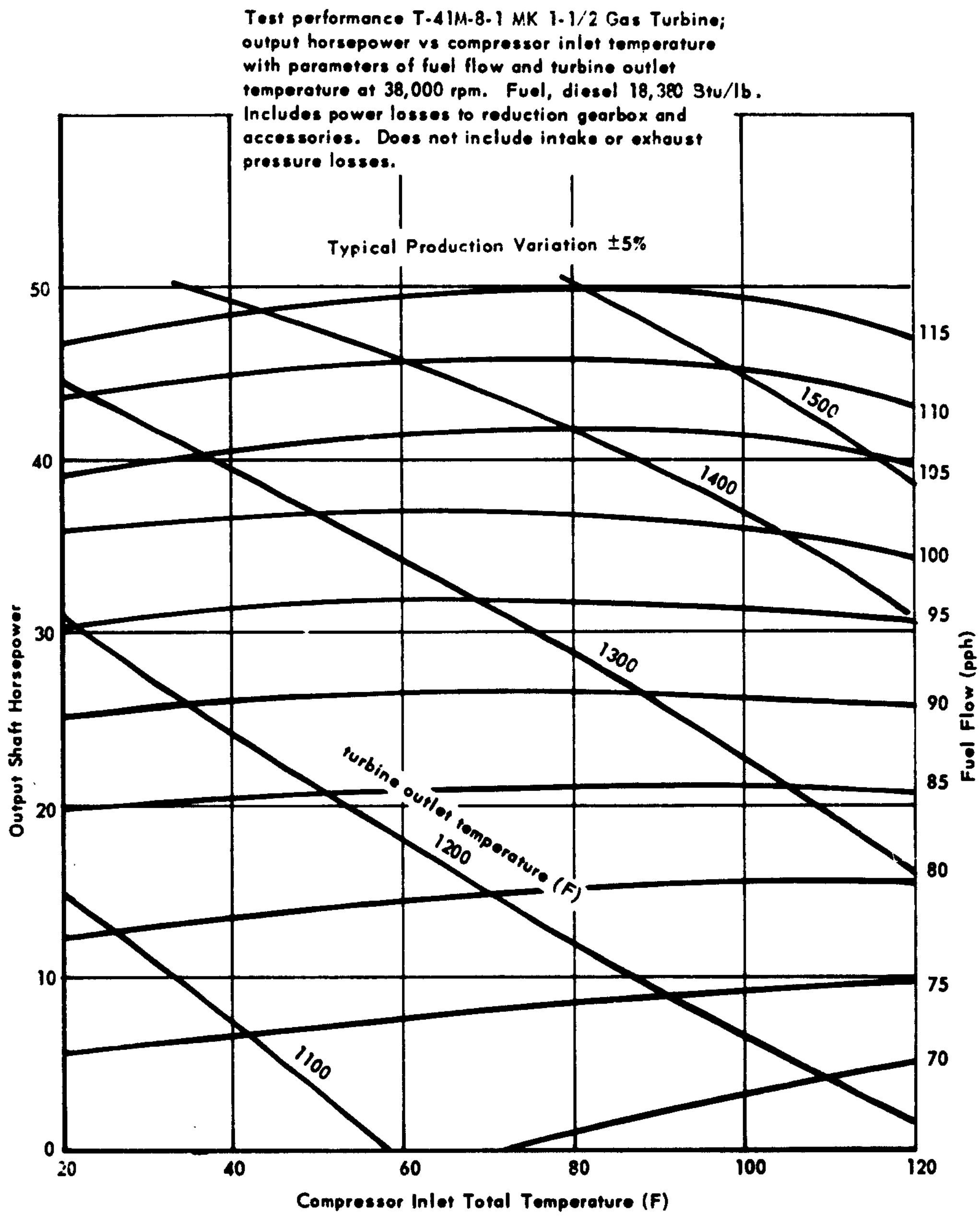


Figure 12. Gas turbine operational characteristics (furnished by the Solar Aircraft Company).

pump control turbine control

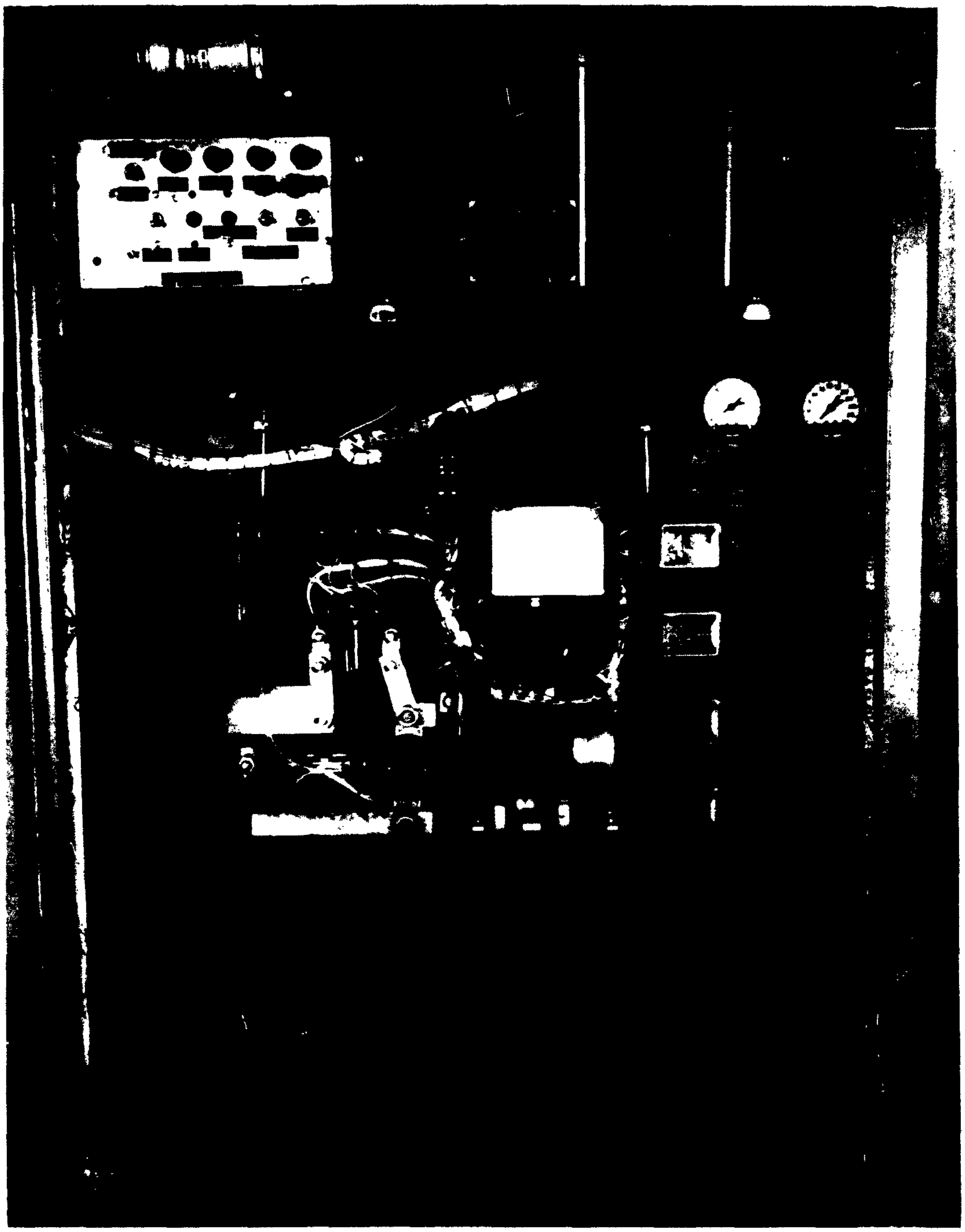


Figure 13. Gas turbine booster station control panel.

A safety device which shuts down the turbine to prevent damage from overload and overspeed conditions operates on a minimum speed variation of plus or minus 2 percent of rated turbine speed. Overload conditions were encountered during the developmental tests of the diesel booster station, and the power requirements imposed on the turbine by the pump were investigated. It was noted from the turbine-characteristic curves (Figure 12) that a maximum of 50 horsepower could be expected from the turbine. The pump-characteristic curves (Figures 14a and b) indicated that the pump requirements of the 6.75-inch impeller (original equipment) would exceed the maximum horsepower of the turbine when pumping over 400 gpm of gasoline and 275 gpm of diesel fuel. The curves for the same impeller revealed that pressures in excess of 150 psi could be expected when pumping fuels in the planned operational ranges. Since a larger turbine was impracticable, the use of a smaller-diameter impeller was investigated. The curves of Figures 14a and b showed that with a 5.75-inch-diameter impeller it was virtually impossible to overload the turbine, and that reasonable fuel-pumping pressures could be expected.

The turbine cannot be brought up to starting speed if any load is imposed on it during starting. Because of this and the direct connection of the pump to the turbine, a quick-acting valve was placed in the piping circuit on the intake side of the pump. The hydraulically operated quick-acting valve is actuated by the pump switch and permits the turbine to be started before fuel is introduced to the pump.

From the standpoint of safety, the turbine has features that warrant special attention in the operating and design requirements; e.g., the electronic-electrical control in the starting, the hot exhaust gases, and the required draining of fuel and oil from the components of the turbine. Solar turbines are primarily designed as auxiliary power units for electrical systems and have never been used to handle hydrocarbon fuels as required in the subject task. A review of the electrical and electronic components of the gas turbine indicated that the electrical system did not comply with the National Electrical Code criteria for hazardous location. The controls did conform to environment-proof requirements of aircraft design specifications and safety precautions in that all spark-producing components were hermetically sealed. As long as the connections remained tight and moisture-free, the unit was presumed nonexplosive.

The electronic components used by NCEL in the turbine booster station controls were designed and/or procured under the same military specifications and standards as those in the Solar turbine; whereas the fuel pumps, pump drain valve, and the discharge - intake controls were explosion-proof in accordance with the National Electrical Code.

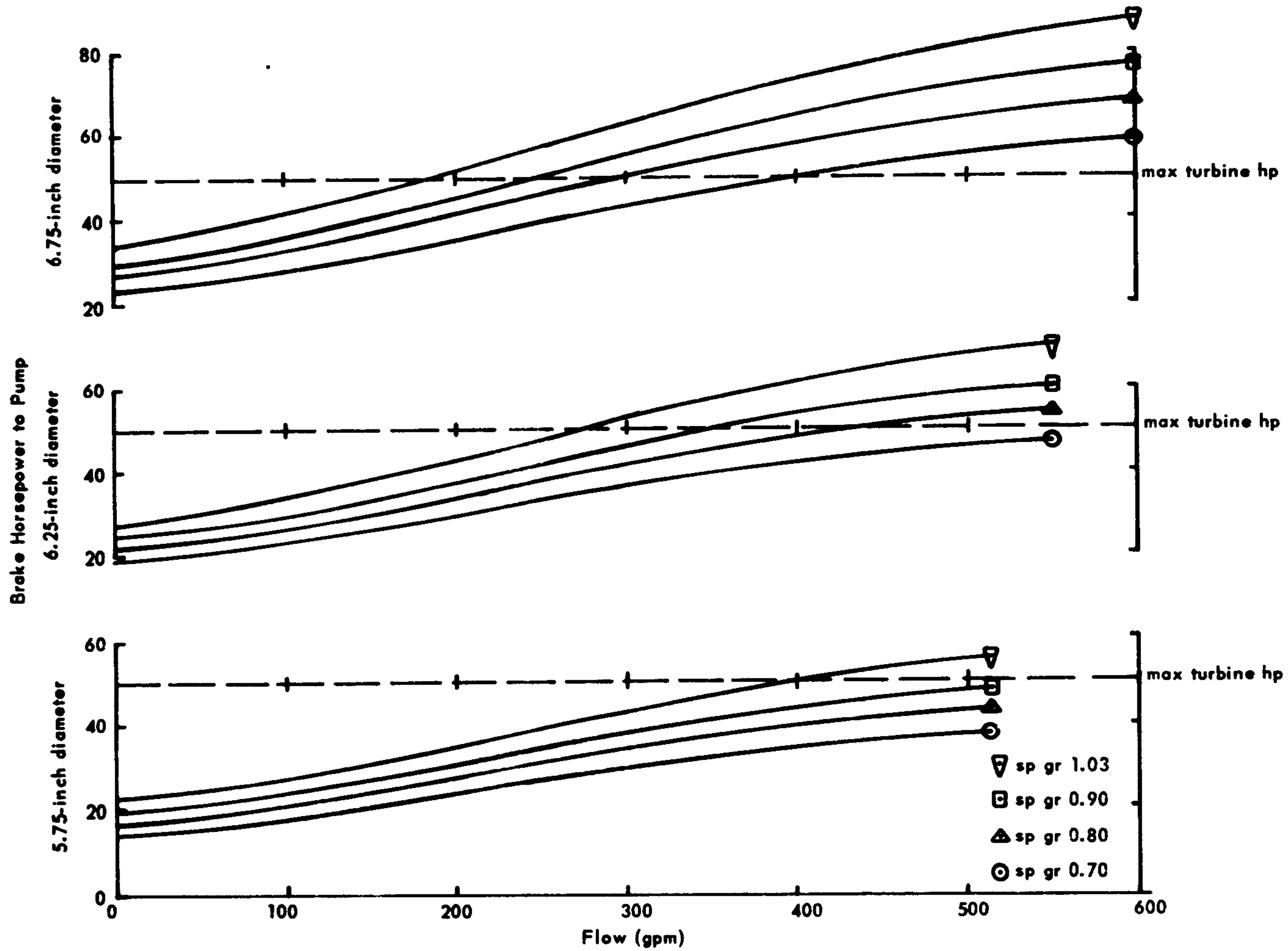


Figure 14a. J. C. Carter P/N6272 fuel-transfer pump characteristics.

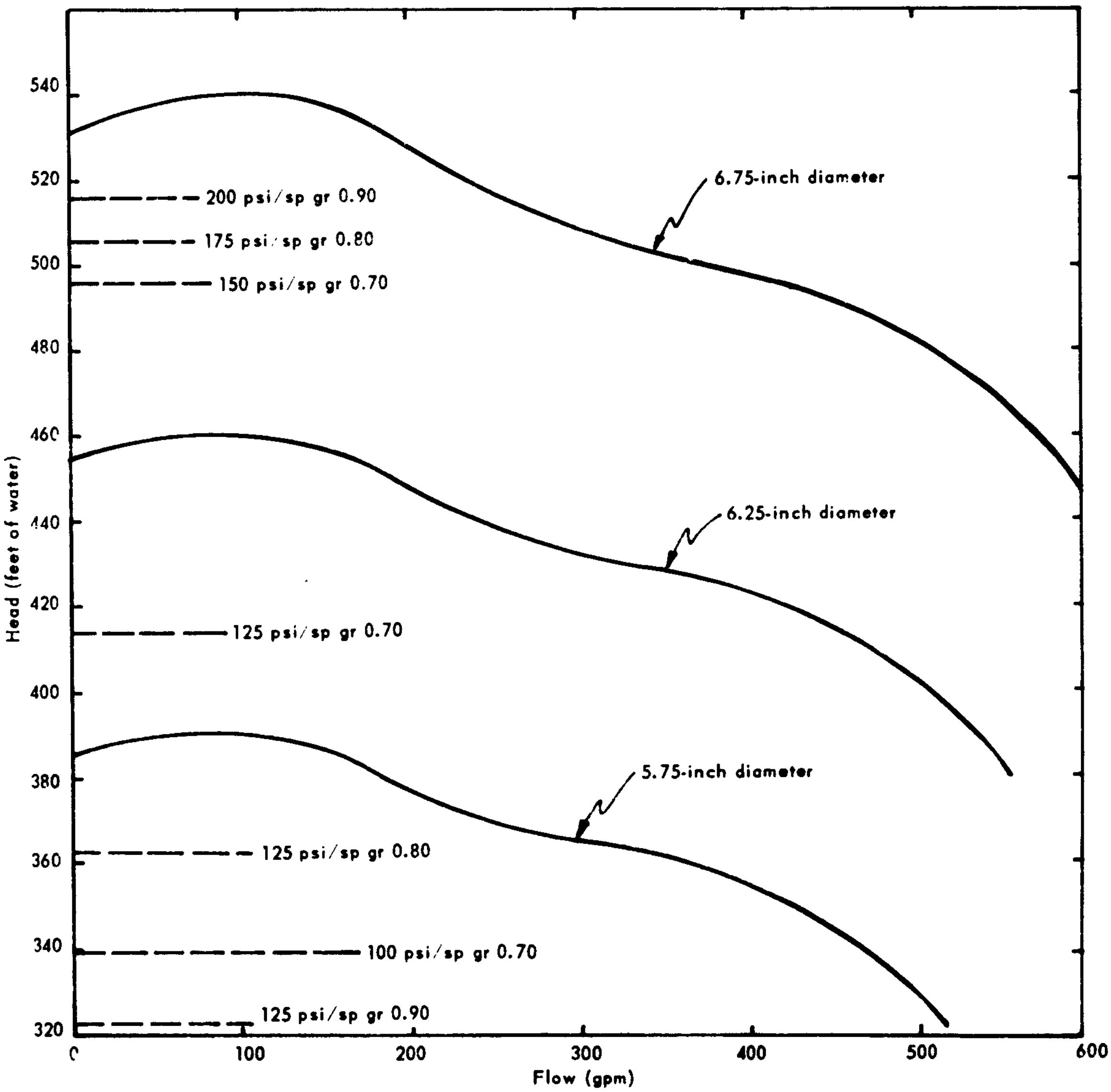


Figure 14b. J. C. Carter P/N6272 fuel-transfer pump characteristics.

To remove fuel and oil (potential fire hazards) from several areas of the turbine, drains were required. Drains were needed for the turbine fuel pumps and the fuel-transfer pump driven by the turbine. The turbine fuel pump required a sight drain to monitor for excessive leakage. The fuel from the fuel-transfer pump was valved off to eliminate a load on the turbine during starting. In both cases, drains emptied into separate containers for later disposal. The turbine scroll drain, in cases of cold starts, voided approximately a cup of hot fuel which had to be removed through a sight drain to a small metal container for later disposal. The scroll drain sump had to be vented to remove the fumes from the hot fuel.

Special ducting was designed to induce air into the turbine and turbine housing from about 6 feet above deck level by means of an inductor in the exhaust stack. Inducted air and exhaust fumes are expelled at a height of 6 feet (Figure 10). The vapor density was not expected to be explosive at this level, but a further guarantee would be to extend the intake and exhaust ducting above the sides of the craft.

Engineering Tests and Results

The initial test was made in the presence of a representative of the Solar Aircraft Company. The first start of the turbine was immediately stopped because no temperature was indicated on the gage. A malfunction in the pyrometer control was repaired and the test was resumed.

The next several starts were interrupted by the NCEL-designed pump-control system, and field modifications included:

1. The discharge pressure-control line takeoff was relocated from a point adjacent to and downstream from the pump to point 1 (Figure 11). This was done because the pressures at the former point were above the operating limit, and therefore activated the high-pressure control, thus stopping the turbine.

2. For test purposes, an additional valve was placed in the system downstream of the discharge valve at point K (Figure 11) to simulate the downstream line pressure. Without this valve, a low discharge pressure would be indicated similar to an empty line, thus causing the low-pressure control to be activated, stopping the turbine.

3. A two-way switch was added to the NCEL-designed pump control panel (Figure 13) to provide for both manual and automatic operation. When in manual operation the pressure control circuits were bypassed until the system pressure could be stabilized with valves D and K (Figure 11).

The discharge pressure at point 2 (Figure 11) was to be maintained between a minimum of 90 psi and a maximum of 120 psi. (The pressure of the internal pump circuit could be higher, up to 150 psi, with no damage.) After the pressure had been stabilized, automatic control could be maintained.

4. A 10-second-delay relay was replaced with a 90-second-delay relay in the turbine shutdown circuit. This was to prevent shutdown caused by momentary surges through the line.

These changes permitted the testing to continue. However, balancing and automatic operation were still difficult to obtain. Additional changes were required before the tests were concluded: (a) the 10-second delay in the turbine shutdown circuit was reinstalled because the longer delay increased the possibility of damage to the turbine; (b) the size of the hydraulic accumulator on the quick-acting valve was increased to provide additional cycles per charging; (c) the action of the quick-acting valve was slowed to decrease the shock load to the pump and turbine; and (d) the operational range of the discharge pressure was increased to a minimum of 85 psi and a maximum of 125 psi.

Subsequent tests were plagued continually with malfunctions in the Carter pump drain valve and the turbine generator control circuit. The pump drain valve was failing to close, subjecting the drain line to the full discharge pressure of the pump (150 psi), which caused fuel to be blown from the drain tank out the vent. Investigation showed that the activating solenoid had been incorrectly installed, thereby prolonging the closing action. When this was corrected, the valve operated with an acceptable 1/2-second delay.

Fluctuations in the voltage of the turbine generator caused intermittent shutdowns. Fourteen such shutdowns were recorded during one day of testing. A fautly relay was replaced and the trouble was ended.

Capacity test results were consistent with the manufacturer's pump-characteristic curves (Figures 14a and b). The tests were discontinued after approximately 20 hours running time on the turbine.

DISCUSSION

Diesel-Driven Booster Station

In general, the diesel-driven booster station operated in a satisfactory manner. Continuous operation within the designed operating pressures is possible with the mechanical-hydraulic control system. Incoming volume and pressure of the booster system must be balanced with the design discharge pressure of 100 psi before automatic operation is possible. The control system for the unit is designed to operate both manually and automatically. Manually, the unit will operate regardless of the intake pressure or the discharge pressure. The manual operation is used for balancing the unit; i.e., establishing an intake pressure of 15 psi and a discharge pressure of 100 psi. Once the unit is balanced, the control system is set in automatic operation and will shut off the diesel engine when any of the design limits for intake pressure, discharge pressure, and pump temperature are exceeded.

Overloading the diesel engine was eliminated by reducing the size of the pump impeller from 9 inches to 7.5 inches. The tests showed that the pump will handle up to 575 gpm of diesel and lighter fuels within the designed pressure limits.

A crew of three, including the vessel operator, is required to operate the station. This entails mooring the vessel, securing the segments of the fuel system to the pump, balancing the system, and monitoring during pumping operations, as described in Appendix B.

Continuous communication between the booster station, the AOG, and the shore is imperative. The booster station personnel should be notified of any change in requirement or delivery rate, so that corrective actions can be taken to maintain the required operational pressures.

Gas-Turbine-Driven Booster Station

The development tests were continually interrupted by the malfunctions in the Carter pump drain valve and the turbine generator control circuit, but indications were that:

1. The pump control performed satisfactorily when operating within the designed pressure limits.

2. The wider range of the discharge-pressure limits (85 to 125 psi) eased the control problems and permitted passage of minor transient pressure surges without interruptions.

3. The pump operation was in agreement with the pump-characteristic curves of Figures 14a and b.

4. The booster pump system must be carefully balanced to maintain the designed intake and discharge pressures.

Some of the electrical components on the unit may constitute a safety hazard. In making or breaking the plug-in connections during normal maintenance or servicing, the possibility of sparking exists. However, once an electrical plug-in connection is made, it is environment-proof and presumed nonexplosive.

A crew of three will be required to operate the gas turbine booster station. The crew will moor the vessel, secure the fuel line to the pump, balance the system, and monitor the pumping operation. Experience has also shown that field repair of the malfunctions is very difficult and will require highly trained personnel.

FINDINGS

In comparison with the gas-turbine booster station, the diesel booster station

1. Is less complicated in design.
2. Has a lower fuel consumption, but will operate only on diesel fuels.
3. Has a lower initial and maintenance cost.
4. Is easier and safer to operate and maintain.

Whereas, the gas turbine booster station

1. Is lighter in weight.
2. Provides full power without warmup in contrast to the 5-minute warmup period required by the diesel engine.
3. Will operate on gasoline, diesel, or jet fuels.
4. Is more difficult and potentially dangerous to operate and maintain.
5. Requires higher-skilled personnel for repairs.

CONCLUSIONS

1. The use of a booster station to increase the effective delivery distance of the 4-inch ship-to-shore bulk fuel delivery system is feasible.

2. The floating booster station is capable of installation and operation in conditions suitable for amphibious operations.

3. The prototype diesel-driven booster station described herein is satisfactory and can be installed, operated, and maintained by amphibious construction personnel.

4. The gas-turbine-driven booster station described herein is unsatisfactory.

RECOMMENDATIONS

It is recommended that the diesel-driven booster station be in-service tested to determine its effectiveness when used with the 4-inch ship-to-shore fuel delivery systems. Further work on the gas turbine booster station is not recommended.

Appendix A

CONTROLS OF DIESEL-POWERED BOOSTER STATION

In the primary stage, a small portion of the fluid from the discharge side of the pump is passed through the normally open temperature-control valve and a high-pressure filter (Figure 6). The fluid is then divided; one portion passes through a metering check valve to furnish pilot pressure to the high-pressure relief valve, and the other portion passes through a similar metering check valve to the valve portions of the normally closed high-pressure relief valve and a normally closed low-pressure relief valve (Figure 7). The metering valves are set to pass sufficient fluid to maintain operating pressures in the primary and secondary circuits and to compensate for the normal leakage through the high-pressure relief pilot valve. Pilot pressure for the low-pressure relief valve is taken from the pump intake line at a point midway between the intake screen and the pump (Figure 6) and passed through.a low-pressure filter to the diaphragm of the low-pressure relief valve (Figure 7).

The secondary stage is a combination hydraulic-mechanical system which converts falling pressure conditions (originating from the high-pressure, low-pressure, and temperature controls) into the mechanical motion required to shut down the diesel engine. This stage also responds directly to any pump-discharge pressure drop in excess of 20 psi.

The secondary stage is automatically cocked during the normal starting procedure of the engine. The cocking rod (Figure 7) is pulled out, carrying with it the fuel-control rod (Figure 8). The fuel-control rod is held in a cocked position by the trip (Figure 8). As the pressure on the system builds up, a small hydraulic ram activates the mechanical portion of the stage (Figure 8). Pressure from the primary stage extends the ram which translates a latch mounted on a pivoting lever to an engagement with a tripper mechanism. The ram is opposed by an adjustable buffer spring through a pivoting lever arrangement.

When a falling pressure condition is induced, the ram retracts. This in turn causes the latch under action of the buffer spring to trip the tripper mechanism, releasing the spring-loaded fuel-control rod, thus stopping the engine.

A control override feature to bypass the automatic operation has been incorporated into the control system. The override is activated by keeping the cocking rod in an extended position; this in turn holds the fuel-control rod in an open position.

Manual shutdown can be accomplished by pulling the stop knob (Figure 9) on the control panel. This lifts the latch, which releases the fuel-control rod, and stops the engine.

The conditions under which the control will function are:

1. When the pump temperature is high, the normally open temperature-control valve closes, shutting off the supply of pressure fluid to the primary stage. The leakage through the high-pressure relief valve pilot induces a falling pressure condition, which activates the secondary stage, thus tripping the final mechanical control.

2. When the discharge pressure is high, the high-pressure relief valve opens, dumping the pressurized fluid in the control circuit through the low-pressure section of the system into the intake side of the pump. This induces the falling pressure condition which stops the engine.

3. When the intake pressure is low, the low-pressure control valve opens, relieving the pressure in the primary stage. This causes the pressure to drop in the secondary stage, tripping the final mechanical control.

4. When the intake pressure is high, it is monitored as a high-discharge pressure condition, and the mechanical control is tripped as described in Item 2 above.

5. When the discharge pressure is low or when pressure drops in the line leaving the pump (as would occur with a rupture), the mechanical control is tripped.

Appendix B

INSTALLATION AND OPERATION OF DIESEL-POWERED BOOSTER STATION

INSTALLATION

The length of the fuel line required to reach a safe water depth for the tanker is first determined and then the eventual positions of the booster station and the tanker are located with marker buoys.

A length of bottom-laid pipeline is installed from the beach to the site of the booster station, and the end of the towing hose is attached to a marker buoy and put over the side. The buoyant hose is then installed from the booster station location to the tanker location, allowing enough slack hose at the booster end for attachment to the pump. Both ends of the hose line are marked with buoys.

The booster station is then moored and, with the aid of a support vessel, the ends of the two fuel lines are retrieved and connected to the booster pump, the bottom-laid pipeline to the discharge side and the hose line to the intake side. Securing the fuel lines to the vessel will ease the strain on the connections at the pump.

The submarine telephone lines from the shore and from the tanker are hooked to a single field telephone on the booster station, establishing a three-party line between the shore, the booster station, and the tanker.

OPERATION

Before starting the diesel engine check to see that:

1. The pump is disengaged from the engine.

2. The discharge valve is closed or only partially open.

3. The automatic control is cocked with the cocking knob out.

The engine is started, using normal diesel engine procedures, and after a 5-minute warmup period, the AOG and shore are notified that the booster station is ready for operation.

When there is fuel in the line (as determined by monitoring the line pressure on the intake side of the pump), the pump is started by engaging the clutch between the pump and the engine. The discharge valve is then slowly opened until an intake pressure of 15 psi is reached and maintained. (The discharge pressure will be approximately 100 psi at this time.) After this balanced stage is reached, the cocking rod is pushed in, placing the booster station on automatic control.

Constant monitoring of the pressure gages on the booster station and continuous communication with the tanker and beach are required for a safe and efficient operation.

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